The Quantum View of the World E.C. Sept. 1981

1. Introduction

One of the most spectacular developments in physics over the last 150 years has been the rise of the atomic theory of matter. But since the early part of this century it has become clear that atoms themselves have structure, a central positively charged nucleus surrounded by a number of much lighter negatively charged electrons. Indeed further probing has shown that the nucleus itself has structure being composed of an assemblage of protons and neutrons, and indeed it has quite recently been shown that these nucleons ~~can~~ themselves are made up of still new elementary constituents – the quarks.

Now when the idea of an inner structure to atoms ~~& so~~ was first proposed it was imagined that the laws governing this structure were similar to those familiar in ordinary macroscopic mechanics, the Newtonian or classical mechanics which had proved so successful in describing for example the motion of the planets round the sun. Indeed this analogy is still often employed when explaining the structure of the atom as made up of nucleus (the sun) and orbiting electrons (the planets).

But it turned out that the laws governing the motions of electrons in atoms, for example, were quite different from those of Newton. A new mathematical theory was proposed which became firmly established in the late 1920s and is known as quantum mechanics to ~~describe~~ account for the ~~phenomena~~ ~~observed~~ properties of ~~atomic sys~~ physical systems of very small size such as atoms ($\sim 10^{-8}$ cm in dimension) and now 2.

$m_e =$ gms

Quantum Mechanics

The new mechanics has two distinctive features

1) Physical quantities such as energy and angular momentum in general ~~have~~ exhibit on measurement only a ~~c~~ discrete set of possible values instead of the continuous set envisaged in classical physics (Discreteness or Quantization)

E.g. if I whirl a stone round on the end of a string its angular momentum can have any old value depending on how fast I whirl the string, or if I drop the chalk to the floor, its kinetic energy ~~changes~~ increases in a continuous way to the value it has as it hits the floor.

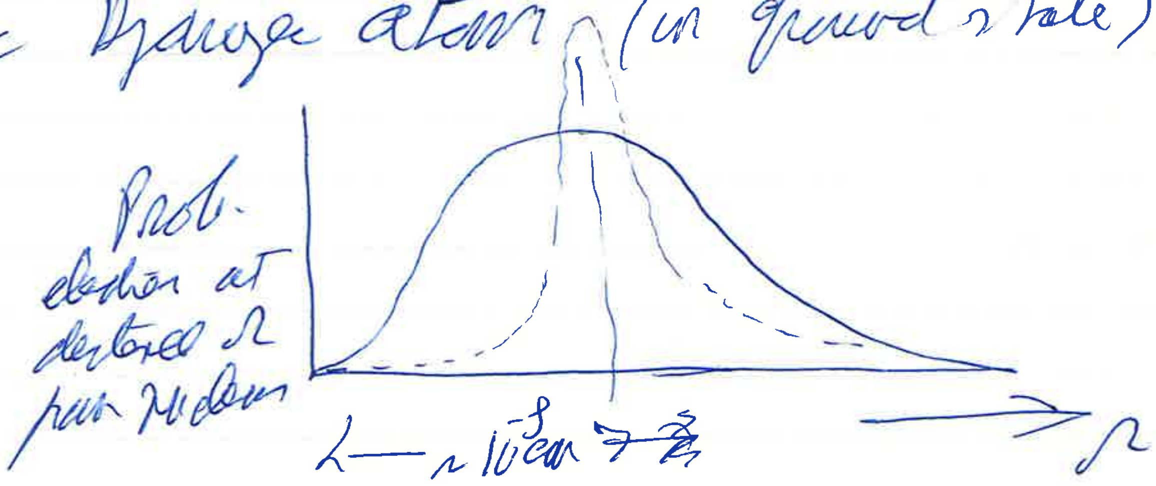
But in quantum mechanics this sort of behaviour is not in general the case. E.g. in the case of angular momentum the theory says $J^2 = l(l+1)\hbar^2$ where l is any integer or half-integer and $\hbar$ is a constant known as Planck's constant ($= h/2\pi \sim 10^{-34}$ J.s)

Furthermore if we write $J^2 = J_x^2 + J_y^2 + J_z$ in terms of its components $J_x\ J_y\ J_z$ then J_x, J_y, J_z take any values from $l\hbar$ to $+l\hbar$ in integral steps. Exs

	J	J_z
$l = 1/2$	$\frac{\sqrt{3}}{2}\hbar$	$\pm 1/2\,\hbar$
$l = 1$	$\sqrt{2}\,\hbar$	$+\hbar, 0, -\hbar$

2) In general the theory does not predict the results of measurements to be made on physical quantities like energy or momentum, but only the probabilities that any given permitted value will be observed.
E.g. in the case of radioactive decay we cannot predict the time at which any particular atom decays but only the probability that it will decay in any given interval of time.
Take the case of position (which is not quantized). Instead of saying how the position of an electron changes along a well-defined trajectory we compute a probability distribution for finding it at any given location.

Ex. Hydrogen atom (in ground state)

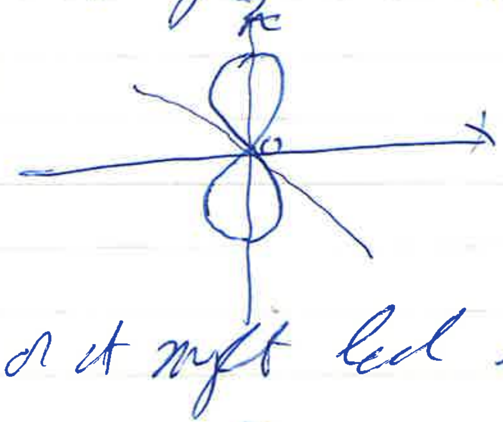


One way of talking here is to say the electron is smeared out like a wave rather than a particle. Indeed the new mechanics is often known as wave mechanics to emphasize this analogy.
But is it only an analogy: Is it not the case that electrons do have

positions, but we don't know what they are?
Take again the case of angular momentum.

In a typical state (2p) of the hydrogen (with $l=1$) atom the angular distribution of its wave function might look like this

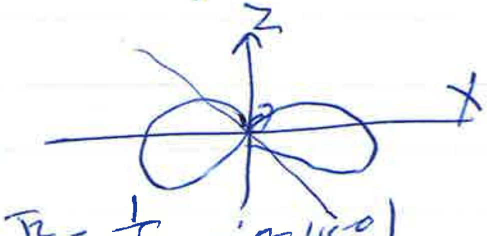
$J_z = 0$



The a.m. points somewhere at right angles to the z-axis

or it might look like this

$J_z = \pm 1$



the a.m. points along the z-axis

(NB) $\cos\theta = \frac{J_z}{J} = \frac{1}{\sqrt{2}}$, $\therefore \theta = 45°$)

but no other orientation of the a.m. is possible, since there would ~~correspond to~~ J_z values of J_z between 0 and 1 in magnitude.

This directional or (spatial) quantization of atomic systems was actually first observed by Stern, Gerlach in a famous experiment some of you may have read about (proposed ~~[illegible]~~ in 1921)

But again the a.m. case there are more complicated states involving only probabilities for observing $J_z = 0$ and $J_z = \pm 1$. just as in the case of position in the first example or the case of J_x, J_y in the above example.

3 The Mathematical problems of rebuilding the formalism.

Can we always assign values to physical quantities.

Two difficulties arise

1) The Kochen–Specker paradox.
2) Nonlocality.

I want now to explain these two problems, although there will not be time to discuss how to resolve the problems.

The Kochen-Specker Paradox

for $l=1$ $\quad J_x^2 + J_y^2 + J_z^2 = 2$

and $J_x^2 = 1, 0$, $J_y^2 = 1, 0$, $J_z^2 = 1, 0$

$\therefore$ 2 out of J_x, J_y, J_z must have value 1 }
1 — — ——— 0 }

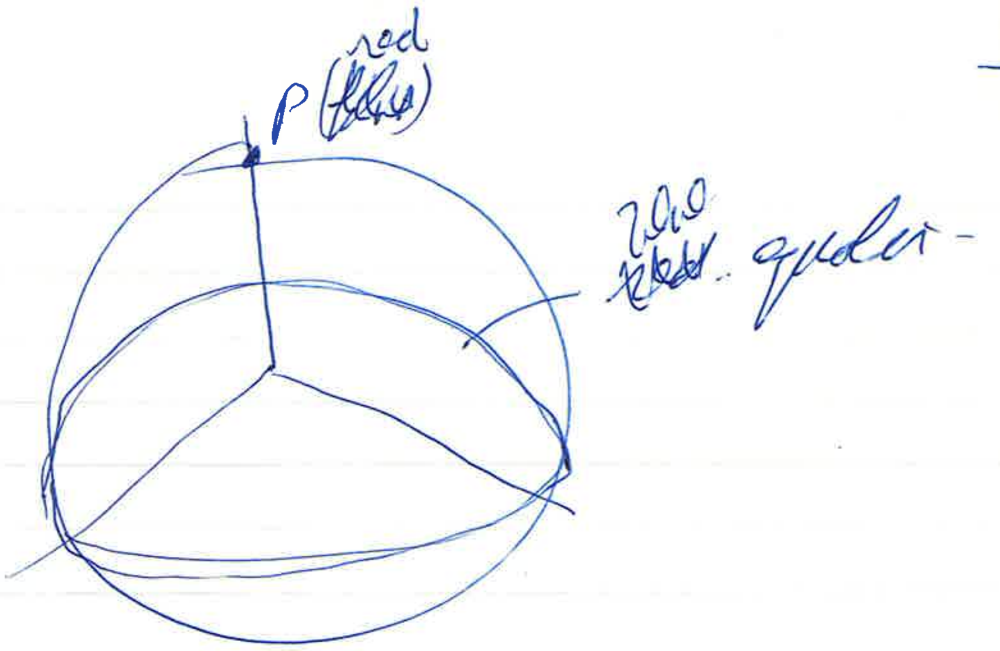
Now repeat the argument for all directions of the x, y, z system

we obtain the following problem:

blue = 1 }
red = 0 }

Can we colour a sphere blue, red so that on all orthogonal triads of axes, one axis is coloured red & the others blue.

Answer This turns out to be impossible


P
red
(~~blue~~)
120
quadr-

we end up with too many red points (closer to as $1/3$ of the sphere)

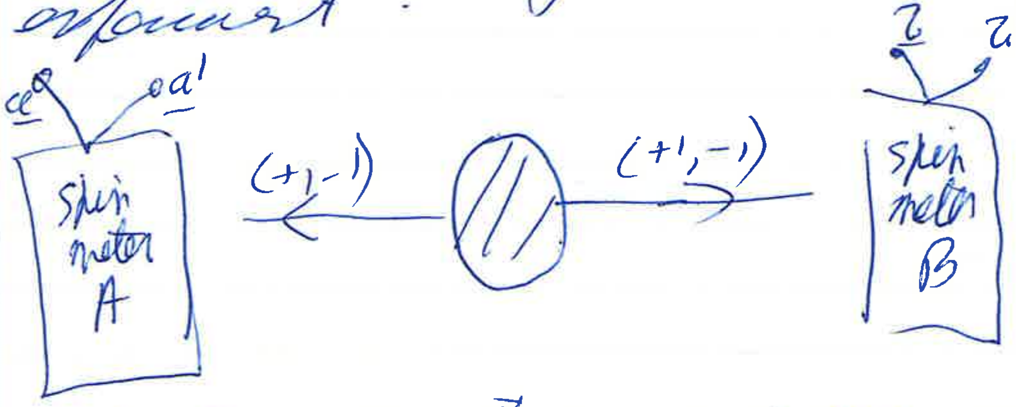
Rigorous proof is an exercise in spherical geometry.

2) Non locality -

Consider two systems widely separated in a [illegible] state with $l=\frac{1}{2}$ for each

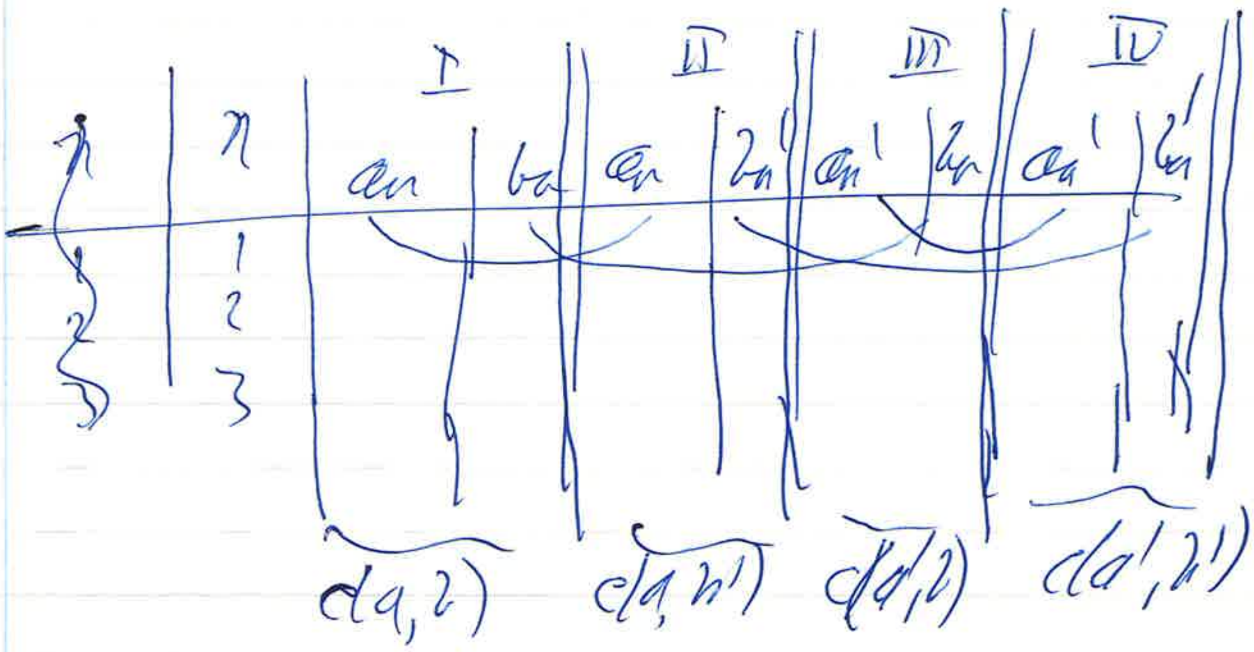
Here J_x, J_y, J_z have values $\pm\frac{1}{2}\hbar$; let us work in units of $\frac{1}{2}\hbar$ and call these possible values ± 1.

Now consider the following correlation experiment.


a
a'
z
z'
(+1, -1)
(+1, -1)
spin meter A
spin meter B

spin components of the nth pair of particles are a_n, a_n', b_n, b_n'

But we have made a locality assumption



ie spin projection of either particle is independent of what measurement procedure is carried out on the other particle.

This locality assumption must be given up in any 'realistic' interpretation

Experiment of Aspect has in effect shown that the nonlocal action is propagated at speeds faster than light — Hence the Times head line
'Random Events versus Einstein'

Locality: The value of a physical quantity cannot ~~can~~ be ~~be~~ changed by altering the arrangement of a remote piece of apparatus.

Concluding Remarks

We may end up rejecting one or other of two assumptions
1) Particles do possess properties independent of whether we are observing them or not

or 2) Nonlocal effects are impossible ~~not allowed~~.

But it can be shown, by a more detailed analysis that no signals can be transmitted (i.e. no information) the Bell telephone is not possible.

So the quantum view of the world is inconsistent with the conventional 2 cherished views about reality
1) It exists ~~between~~ behind the world of appearance (observation)
2) It is governed by laws of local action (foundation of relativity theory).